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COMPREHENSIVE LONG-TERM ENVIRONMENTAL ACTION NAVY

CLEAN II

THERMATRIX NELP TECHNOLOGY DEMONSTRATION REPORT
NAVAL AIR STATION
NORTH ISLAND
SAN DIEGO, CALIFORNIA
CTO-0008/0694

Prepared by:

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ACRONYMS/ABBREVIATIONS

BNI	Bechtel National, Inc.
CLEAN	Comprehensive Long-Term Environmental Action Navy
CO	carbon monoxide
COC	compound of concern
CRF	capital reduction factor
CTO	Contract Task Order
DON	Department of the Navy
DRE	destruction and removal efficiency
FID	flame ionization detector
GC	gas chromatography
IDW	investigation-derived waste
kWh	kilowatt-hour
µg/kg	microgram per kilogram
µg/L	microgram per liter
mg/kg	milligram per kilogram
mg/L	milligram per liter
NAS	Naval Air Station
NELP	Navy Environmental Leadership Program
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
O&M	operation and maintenance
O_2	oxygen
PDO	primary demonstration objective
PICS	products of incomplete combustion
PM	project manager
POC	point of contact
ppm	parts per million
psig	pounds per square inch (gauge)
QC	quality control

ACRONYMS/ABBREVIATIONS (continued)

RACT	Reasonably Available Control Technology
scfh	standard cubic feet per hour
scfm	standard cubic feet per minute
SDAPCD	San Diego Air Pollution Control District
SDO	secondary demonstration objective
SHSO	Site Health and Safety Officer
SWDIV	Southwest Division Naval Engineering Facilities Command
THC	total hydrocarbons
TNMHC	total nonmethane hydrocarbons
U.S. EPA	United States Environmental Protection Agency
VOC	volatile organic compound

Section 1
INTRODUCTION

The objective of this project is to demonstrate the ability of the Thermatrix, Inc. (Thermatrix) flameless thermal oxidizer technology to provide a technically sound and cost-effective treatment of organic emissions at Naval Air Station (NAS) North Island. This demonstration was conducted under the auspices of the Navy Environmental Leadership Program (NELP).

This section provides background information about NELP, the site, the waste stream, and the technology used for this demonstration.

1.1 NAVY ENVIRONMENTAL LEADERSHIP PROGRAM

On October 23, 1993, the Secretary of the Navy approved the NELP for implementation at NAS North Island and Naval Station Mayport in Florida. NELP was established as a Navy initiative to focus on finding new and innovative ways to manage environmental programs at Navy bases. NELP demonstrates innovative environmental cleanup, compliance, conservation, and pollution prevention technologies and controls. The two Navy bases selected to implement NELP act as prototypes to develop, test, and refine initiatives for all aspects of shore station environmental programs. When successful, the technologies are exported Navy-wide to accelerate cleanups and improve environmental management techniques.

Thirty-seven new and innovative technology projects, such as this Thermatrix flameless thermal oxidizer technology demonstration, have been initiated or are under way at NAS North Island.

Detailed project summaries are provided in the NAS North Island NELP Program Guide, April 1995.

1.2 SITE DESCRIPTION

The Fuel Farm, which is located at the northwest corner of NAS North Island and comprises approximately 18 acres, was chosen by Thermatrix as the demonstration treatment area (see Figure 1-1). Within the Fuel Farm area there are a number of fuel storage and transfer operations which are known sources of fugitive emissions (see Figure 1-2).

1.3 WASTE STREAM DESCRIPTION

Tank 1009, an underground JP-5 fuel storage tank located at the Fuel Farm, was selected as the vapor source for the NAS North Island demonstration because the transfer and dispensing of JP-5 is a frequent activity at the tank, and the resulting emissions provide an adequate flow rate and concentration of volatile organic compounds (VOCs) for the thermal oxidizer. The tank is exempt from San Diego Air Pollution Control District (SDAPCD) permit requirements as an emission source. During normal operations, vent gas from Tank 1009 is discharged from dual elevated pressure/vacuum relief vents to the atmosphere as the tank is filled. For the NAS North Island demonstration, 1-inch polypropylene tubing was inserted into both tank vents to allow a slipstream of vapor to be drawn into the Thermatrix oxidizer unit.

1.4 DEMONSTRATION TECHNOLOGY DESCRIPTION

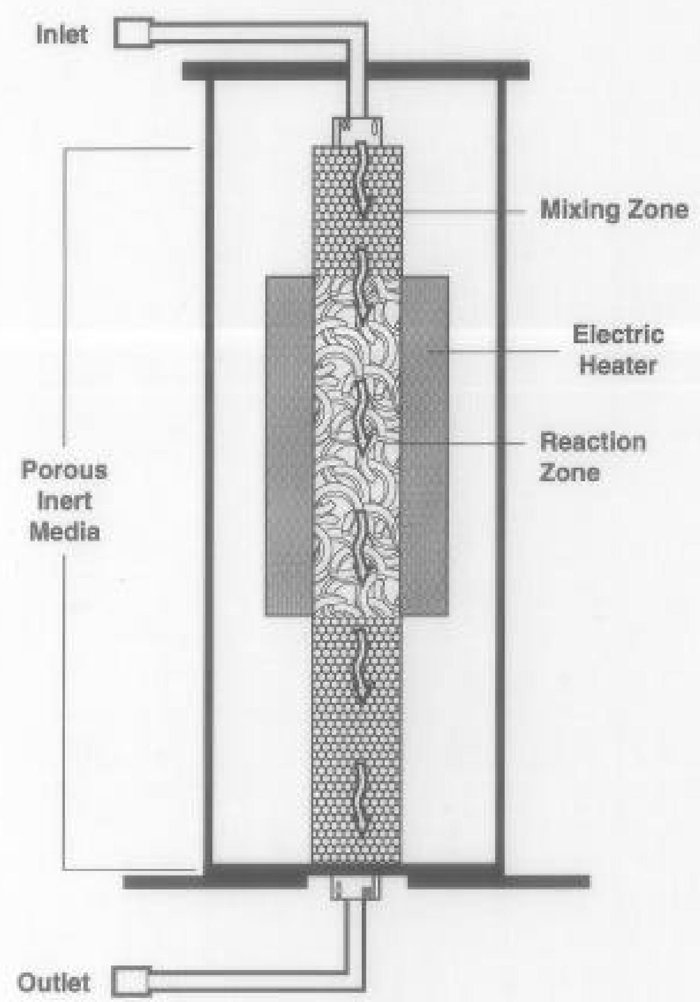
The Thermatrix flameless thermal oxidation technology uses a non-flame, packed-bed oxidizer to destroy VOCs. The unique feature of the oxidizer is its use of a hot, stationary bed of inert ceramic material. The ceramic matrix provides turbulence for the mixing of gases and, therefore, the oxidizer does not rely on a flame for gas mixing. The ceramic matrix also provides consistent temperatures and ensures complete oxidation of hydrocarbons. The large heat sink provided by the ceramic matrix allows the oxidizer to treat waste fumes from either continuous or batch processes. Since the bed is composed of chemically inert material and is not catalytic, the oxidizer can handle a wide variety of VOCs, and performance of the bed is maintained throughout the life of the system. The use of a non-catalytic matrix avoids the chance of poisoning or sintering the matrix. Also, in contrast to catalytic oxidizers, pressure drop across the system is very low due to the high void space ratio (i.e., approximately 70 percent) in the matrix.

Due to much lower peak temperatures than those experienced with incineration, insignificant formation of nitrogen oxides (NO_X) and carbon monoxide (CO) are typically expected to occur during oxidation.

In operation, the VOC process stream and any air necessary to support the oxidation reaction enter the oxidizer (see Figure 1-3) and flow into the ceramic matrix, which has been preheated to temperatures typically between 1600-1850°F. The Thermatrix unit provided for the NAS North Island demonstration was equipped with internal electric elements for heating the ceramic matrix. Larger units require the oxidation of fuel (e.g., natural gas or propane) for heating. As the fume moves through the interstitial spaces of the ceramic matrix, turbulence results in thorough mixing of oxygen and organics in a mixing zone. The tortuous pathway also provides for heat transfer between the gas and the bed material. The temperature of the gas increases until the oxidation temperature of the organics is attained. Once the oxidation temperature has been reached, the organics in the process stream oxidize in a reaction zone and release heat. A portion of the heat released from the oxidation reaction is absorbed by the ceramic bed to maintain the reaction zone temperature. Both internal and external heat recovery are available on larger capacity units, if desired. The thermal mass of the ceramic matrix allows the oxidizer to efficiently remain in operational standby during treatment of intermittent streams. Photographs of the thermal oxidizer unit provided for the demonstration by Thermatrix are included in Appendix A.

Figure 1-3

Thermal Oxidizer Schematic



Thermatrix Flameless Thermal Oxidizer
NELP Demonstration
Figure 1-3
Thermal Oxidizer Schematic

Naval Air Station-North Island, San Diego, California

Bechtel National, Inc.
CLEAN II Program

Date: 2/6/96
File No. thermox2.ai
Job No. 22214

Control of the oxidation process is fully automated. Thermocouples are used to measure the temperature profile in the reaction zone. The oxidizer control system will allow heat or air to be added in order to maintain the reaction zone in the appropriate geometric location within the unit. If the flow or concentration of the inlet stream increases substantially, dilution air is added automatically at the mixer to keep the reactor within the operating temperature range. If the process stream lacks sufficient enthalpy to maintain the ceramic matrix temperature, thermal energy is automatically introduced into the system. The control system also includes limit switches and alarms that will automatically shut down the unit and activate the appropriate annunciator lights on the control panel when an abnormal condition occurs.

The Thermatrix technology is directly applicable to the treatment of VOC streams. Contaminants amenable to treatment include aromatics, olefins, paraffins, ketones, alcohols, and chlorinated solvents. If chlorinated hydrocarbons are present in the VOC stream, a scrubber to remove acid gas from the thermal oxidizer exhaust can be provided if needed.

Key features offered by the Thermatrix flameless thermal oxidizer that were considered in its selection for NELP include the following:

- Innovative: the oxidizer is a non-incineration, energy-efficient VOC abatement technology; its recuperative design allows heat capture and reuse.
- Safe: the heat capacity and geometry (i.e., high quench surface area and tortuous pathways for flow interruption) provide inherent flame arresting properties; operation is inherently safe due to no moving parts, all internal processes, and surface temperatures that are low and shielded.
- Efficient: enhanced energy efficiency is provided through a recuperative design that reuses the heat of oxidation; the oxidation reaction can be self-sustaining, with no supplementary fuel or heat required after preheating.
- High performance: the oxidizer provides very low thermal formation of oxides of nitrogen (NO_X); it avoids the formation of products of incomplete combustion; it achieves exceptionally high destruction efficiencies on a wide range of organics, including halogenated compounds.
- Reliable: the oxidizer has no moving parts; the oxidizer's significant thermal inertia provides process stability, with simple process control requirements (e.g., fuel and/or air supplementation).
- Low capital and operating costs: the oxidizer is configured with commercially available components selected for high operational reliability, safe operation, and minimum operating and capital costs.
- Chemically resistant: the matrix consists of inert, heat resistant ceramic that is not poisoned or thermally deactivated, and avoids the high initial cost and replacement cost of noble metal-coated packings.

Section 2
DEMONSTRATION APPROACH

Thermatrix proposed to demonstrate its flameless oxidation technology designed to treat emissions of VOCs. This section summarizes the objectives of the technology demonstration, describes the procedures and methods used to sample and analyze the process streams, and documents any deviations from the Work Plan.

2.1 DEMONSTRATION OBJECTIVES

Primary demonstration objectives (PDOs) were established by Bechtel National, Inc. (BNI) in its quality assurance project plan (Bechtel 1995) to assess the effectiveness of the technology for possible treatment of VOC emission sources located at NAS North Island. These PDOs define the compounds of concern (COCs) and establish measurements that will be used to determine the success of the demonstration. The PDOs are intended to verify:

- the effectiveness of the Thermatrix flameless oxidation technology as determined by a destruction and removal efficiency (DRE) >99.99 percent using, as a basis, total hydrocarbons (THCs), and
- that the Thermatrix flameless oxidation technology does not generate more than 2 parts per million (ppm) of NO_X and 10 ppm of CO.

The first PDO addresses the regulatory requirements for control of organic emissions. The typical DRE requirement for hazardous substance incineration is 99.99 percent based on the principal organic hazardous constituent. Use of this DRE requirement for a nonhazardous source is considered a conservative DRE goal, since nonhazardous sources are typically required to achieve only a 99 percent reduction in VOCs. Thus, the first PDO is to compare the performance of the flameless oxidation technology to the performance typically required of hazardous substance incinerators. To complete the calculations for the DRE, the inlet flow rate was also measured as part of this PDO.

The second PDO addresses the emission of the priority pollutants NO_X and CO. Current regulations of the SDAPCD are applicable to NO_X and CO emissions. NO_X, calculated as nitrogen dioxide NO_2 at 3 percent oxygen on a dry basis, cannot exceed 125 ppm. Since the technology has achieved NO_X emissions at 2 ppm, well within this limit, the PDO for NO_X was set at 2 ppm. CO emissions during successful oxidizer operation typically do not exceed 10 ppm. Since no established regulatory levels were defined for CO, Thermatrix proposed that the oxidizer unit demonstrate CO emissions below 10 ppm.

Thus, the COCs for this demonstration are: THCs, NO_X, and CO. In addition, the percentage of oxygen (O_2) will be measured to provide a basis for the concentrations of COCs, the inlet flow rate will be measured for the DRE calculation, and the moisture will be measured.

A secondary demonstration objective (SDO) was established to assess whether the operation of the flameless oxidation technology is acceptable and consistent with

Department of the Navy (DON) environmental and health and safety requirements (BNI 1995). Although this objective is not a direct measure of the technology's performance, it may become an important consideration in pilot- or full-scale implementation of the technology at the site. The SDO was established for information purposes rather than as a means of directly measuring the success of the technology. The operation of the oxidizer is considered "acceptable" and consistent with the DON environmental and health and safety requirements if the following conditions are met:

- the DRE planned under the first PDO is consistently achieved,
- measurement of the power consumption required by the oxidizer unit can be made,
- generation of NO_X, CO, and THCs are at acceptable levels (as stated above), and
- operational incidents requiring services beyond those established in the Work Plan are absent.

This SDO also helped to establish information on operator-attention requirements, utility requirements, and overall safety during operation.

2.2 DEMONSTRATION DESIGN

The experimental design of the measurements to be made to assess the achievement of PDOs and SDOs consisted of the following:

- classifying the types of measurements needed to collect critical and noncritical data,
- determining the measurement frequency, and
- determining the collection method for each data type.

The physical and analytical measurements made during the demonstration were classified as either critical or noncritical. Critical measurements are those that support the PDOs, that is, demonstrating effective removal or destruction of the COCs. The level of quality control (QC) for these data is more stringent than for the SDO, with quantified QC criteria required to ensure data quality. Critical measurements include all of the analytical measurements, including continuous monitoring data, related to the total concentration of the COCs. Vapor samples were collected or monitored at the flameless oxidizer inlet and outlet for all critical measurements. Noncritical measurements support both the PDOs and the SDO. These measurements were made for both computational and information purposes. The critical and noncritical measurements made during the NAS North Island demonstration are presented in Table 2-1.

Table 2-1

Critical and Noncritical Measurements

Critical Measurements	Noncritical Measurements
Measurement of total hydrocarbons (THC) in the treated and untreated vapor streams	Measurement of O_2 content in the treated vapor stream
Measurement of NO_X and CO in the treated vapor stream	Measurement of the thermal oxidizer vapor flow rate
	Power consumption during the period of operation
	Review of logbooks and field notebooks for incident reporting

2.3 EQUIPMENT AND MATERIALS

The Thermatrix model ES-300H thermal oxidizer was provided for the NAS North Island demonstration. The ES-300H unit has a total weight of 1200 pounds and is vertically mounted on a 2-foot by 4-foot skid. The rated performance for model ES-300H is:

- flow rate - 300 standard cubic feet per hour (scfh),
- operating temperature range - 1550°F to 1800°F, with a normal setpoint of 1600°F,
- gas composition - air contaminated with up to 1.8 volume percent hydrocarbons (as propane),
- DRE - greater than 99.99 percent,
- operating pressure - 130-inch water column (negative) to 50-inch water column (positive), and
- reactor cartridge pressure rating - 250 pounds per square inch gauge (psig) (at normal operating temperature).

Additional design details of the ES-300H unit are included in the Thermatrix demonstration Work Plan (Thermatrix 1995).

DON provided a portable air compressor and receiver to supply compressed air for the ES-300H eductor and to purge the control panel. Air provided to the ES-300H unit must be at least 13 standard cubic feet per minute (scfm) at 80 psig, clean, dry, and oil-free.

Sampling and analysis equipment and reagents required for this demonstration are described in the appropriate test methods (see Section 2.4, Sampling and Analysis) and are not included in this report.

2.4 SAMPLING AND ANALYSIS

The purpose of sampling during this technology demonstration was to obtain physical and analytical measurements that support the demonstration objectives as described in Section 2.1.

2.4.1 Sampling Locations

A 1/4-inch-diameter probe was placed in both the inlet and outlet gas streams to allow sampling for methane and total nonmethane hydrocarbons (TNMHC). In addition, a 1/2-inch probe was fabricated concentrically around the 1/4-inch probe in the outlet to allow measurement of NO_X, CO, and O_2. The probes extended into the approximate center of the respective gas streams.

2.4.2 Hydrocarbon Measurements

Measurements of methane and TNMHC were used to establish the THC in the oxidizer inlet and outlet process streams. Sampling for methane and TNMHC was performed in accordance with SDAPCD Method 18 (Radian 1995a). Samples of the inlet and outlet process streams were extracted using 1/4-inch probes, routed through glass fiber filters, and collected in 6-liter, SUMMA® passivated stainless steel canisters. Each canister was equipped with a variable orifice controller to regulate the sample flow rate and a stainless steel pressure gauge to measure the canister vacuum. Three sampling events were conducted (i.e., June 23, June 27, and July 6, 1995). Duplicate inlet and outlet samples were collected during each sampling event. One blank sample was also collected during each sampling event. Methane analysis of the samples collected during the test runs was performed by gas chromatography/flame ionization detection (GC/FID) as described in SDAPCD Method 18. TNMHC concentrations were determined by cryogenic concentration of an aliquot of the sample and subsequent analysis by GC/FID as described in U.S. Environmental Protection Agency (U.S. EPA) Method TO-12 (Radian 1995a). Laboratory analyses were performed by:

Performance Analytical, Inc.
20954 Osborne Street
Canoga Park, CA 91304
Contact: Michael Tuday (818) 709-1139

2.4.3 NO_X, CO, and O_2 Measurements

SDAPCD Method 20 (Radian 1995a) was used to measure NO_X, CO, and O_2 in the system outlet gas stream during the three hydrocarbon sampling events (i.e., June 23, June 27, and July 6, 1995). The monitoring system for NO_X, CO, and O_2 consisted of the following equipment configured as described in SDAPCD Method 20:

- a 1/2-inch stainless steel probe,

- a sample conditioner consisting of two impingers immersed in a mixture of dry ice and 50:50 ethylene glycol and water solution,
- a heated Teflon line to transport the gas sample to the impinger setup, and
- a leak-free nonreactive pump to extract the gas sample from the outlet process line and supply the gas sample to the gas analyzers.

The continuous analyzers used to measure NO_X, CO, and O_2 in the conditioned exhaust gas sample are listed below:

- Thermo Environmental Company Model 10S chemiluminescent NO_X analyzer equipped with a molybdenum converter,
- Automated Control Systems Model 3400 infrared CO analyzer, and
- Teledyne Model 320 AX electrochemical cell O_2 analyzer.

Photographs of the sampling train for the continuous analyzers are included in Appendix A.

Measurements for NO_X, CO, and O_2 consisted of three 45-minute runs. For the first 30 minutes of each run, the NO_X analyzer was operated in the NO_X mode. During the last 10 minutes of the run, the NO_X analyzer was operated in the nitric oxide (NO) mode. U.S. EPA Protocol 1 gases were used for multipoint calibrations, single-point calibration checks, and NO system integrity checks. A certified Scott Master Gas mixture of NO_2 in air was used for the NO_2 system integrity checks. A summary of analyzer operating ranges, calibration gas concentrations, and procedures for pre-test checks and post-test checks is provided in the source test results report (Radian 1995b).

2.4.4 Operating Parameter Measurements

A Diamond II annubar and a differential pressure gauge were installed in the oxidizer inlet piping to obtain flow measurements during the source test. At observed operating conditions, this flow measurement was anticipated to be within ±1 percent. Flow data were also collected from the existing rotometer installed on the oxidizer inlet to provide backup information to the annubar data. In addition to flow rate, reaction zone temperatures and outlet temperatures were also monitored. Flow and temperature data were recorded on log sheets every 10 minutes during each sampling event.

2.5 DEVIATIONS FROM THE WORK PLAN

No significant deviations from the Thermatrix Work Plan (Thermatrix 1995) occurred during the demonstration.

Section 3
RESULTS AND DISCUSSION

A summary of the thermal oxidizer unit operation is presented in this section. In addition, a discussion of key results, including quality assurance and QC, are provided in this section. Key contacts for future reference are also provided.

3.1 SUMMARY OF OPERATIONS

This section provides a summary of activities which occurred during the installation, startup, operation, shutdown, and demobilization of the thermal oxidizer. In addition, measures taken to protect the health and safety of personnel in the vicinity of the thermal oxidizer are described.

3.1.1 Installation

The Thermatrix ES-300H demonstration unit was shipped to the NAS North Island Fuel Farm on May 8, 1995. Installation activities occurred over a 5-day period beginning May 30. The unit was removed from its shipping crate and positioned at the demonstration site adjacent to the airfield on May 30. The air compressor and power transformer were also positioned on the same day. On May 31, the fume inlet and exhaust trains were constructed, plumbing for the instrument cabinet air purge line was installed, and the oxidizer skid and air compressor were anchored to previously installed concrete pads. The support panel for the load center, transformer, kilowatt meter, and reset and shutoff box was constructed on June 1. On June 2, the electrical components were mounted on the support panel. Approximately 50 feet of 1/2-inch polypropylene tubing was also installed on June 2 from the two relief vents at Tank 1009 to the oxidizer inlet. On June 5, electrical connections and inlet plumbing were completed, and air hoses were connected from the air compressor to the exhaust eductor and instrument purge ports.

3.1.2 Startup and Operation

On June 6, 1995, the air compressor was energized and its output adjusted to maintain steady flow to the eductor while minimizing the "on" time of the compressor. The oxidizer was energized in the SHUTDOWN mode, the voltage to the unit was confirmed, and the programmed temperature controller settings were verified. The oxidizer was then put in the RUN mode and the design temperature of 1600°F was achieved in approximately 5 hours. The oxidizer was allowed to run in automatic mode overnight, and on the morning of June 7 the temperature was observed to be 1600°F. Eductor flow was increased until the flow rate measured at the inlet was 300 scfh. However, at this flow rate, the unit did not maintain the design temperature of 1600°F. Flow rate was subsequently reduced to 200 scfh and temperature was maintained at the setpoint. Fuel was then transferred into Tank 1009 and the oxidizer began processing hydrocarbon vapors. During this initial transfer, hydrocarbon measurements were conducted to confirm the THC concentration in the vent stream and to provide health and safety information for operating personnel (see Section 3.1.3, Health and Safety).

On June 8, the 1/2-inch tubing from the tank vents to the oxidizer was replaced with 1-inch polypropylene tubing to decrease system pressure drop and to facilitate sampling at the inlet manifold. Once again, the maximum inlet flow at which the oxidizer could maintain a reaction zone temperature of 1600°F was 200 scfh.

Several scheduled tank transfers were conducted during the next 3 days to verify the ability of the oxidizer to operate continuously and unattended. The duration of each tank transfer operation was approximately 1 hour. Anemometer readings collected during the transfer episodes indicated a flow rate of approximately 1,000 scfm across each of the 8-inch-diameter vents.

Following startup, periodic observation of the unit was provided on week days by Fuel Farm field technicians. Daily monitoring was conducted to ensure that: (1) the sample lines remained inserted in the tank vents, (2) the fume solenoid valve was energized, (3) operating limits were "normal", (4) the reaction zone temperature remained between 1575°F and 1625°F, and (5) the air compressor was operating. A log was maintained in which date, time, unit temperature, exhaust temperature, power meter reading, and the technician's initials were recorded.

3.1.3 Health and Safety

During the installation, startup, and commissioning activities, the Thermatrix Site Health and Safety Officer (SHSO) conducted field gas monitoring to: (1) ascertain background hydrocarbon levels in the demonstration area, (2) track ground-level flows of JP-5 vapor during tank fillings, and (3) confirm safe levels of hydrocarbon exposure for the operator of the oxidizer unit. The SHSO used a Foxboro OVA-128 to measure high hydrocarbon concentrations (i.e., in the tank vents) and a Foxboro OVA-108 to determine a background concentration at the demonstration area. Hydrocarbon concentrations at the ground area beneath the elevated tank vents were typically 100 ppm, which dissipated with distance. At the location of the demonstration equipment, background concentrations ranged between 1.5 and 2.5 ppm THC (as methane), which was below the action level of 5 ppm established by Thermatrix.

The demonstration area was cordoned off with yellow rope on stanchions, and an "Authorized Personnel Only" sign was installed on the electrical components support panel. Equipment guards were in place to prevent injury to personnel from moving or heated equipment. A fire extinguisher was also placed at the demonstration area.

3.1.4 Demobilization

On September 5, a Thermatrix representative verified that the oxidizer had not processed fumes during the period immediately preceding shutdown, and that it had been operating on ambient air at the design temperature to ensure the destruction of any residual organic vapors. On September 6, the oxidizer unit was uncoupled from the utilities, and the air compressor and electrical equipment were removed from the demonstration area. A final inspection of the unit was subsequently performed. No condensate was found in the knockout pot, and no indications of equipment damage were observed. The unit was prepared for shipping and was transported off site by truck on September 6.

3.2 DATA ANALYSIS AND INTERPRETATION

This section provides an analysis of data collected during the demonstration and compares the data with the objectives established for this demonstration.

3.2.1 Analysis of Demonstration Data

The arithmetic averages for methane and TNMHC detected in the thermal oxidizer inlet during the source test are 2,053 ppm and 11,117 ppm, respectively (Radian 1995b). Arithmetic averages for methane and TNMHC in the oxidizer outlet are less than 0.8 ppm and 0.9 ppm, respectively. These analytical results indicate a significant reduction of VOCs following oxidation. Analytical results for methane and TNMHC in the thermal oxidizer inlet and outlet streams are summarized in Table 3-1. Results for methane detected below the method reporting limit are reported at that limit and preceded by a "less than" symbol. The TNMHC results are referenced to carbon. There were no problems observed during the sampling events that would significantly affect the data. Laboratory data are provided as Appendix B to this report.

Continuous monitoring data for NO_X, CO, and O_2 in the oxidizer outlet stream are also included in Table 3-1. Values for these gaseous emissions are consistent for all three sampling events. NO_X values have been corrected to 15 percent O_2 because the O_2 content of the process stream was nearly equivalent to the ambient O_2 concentration. Correction of the NO_X values to 3 percent O_2, as stated in the second PDO, would not have been appropriate.

Prior to filling the sample canisters during the three test runs, the oxidizer eductor flow was adjusted to maintain 300 scfh as measured by the annubar installed on the inlet. The oxidizer control system was capable of maintaining a reaction zone temperature of 1600°F at this flow condition. The inlet flow rate averaged 4.88 scfm (or 293 scfh) for the three test runs, which is 98 percent of the design flow rate for the demonstration unit. Dilution air was not required for the incoming process stream because of the relatively lean organic content. Therefore, the outlet flow rate was assumed to be the same as the flow rate measured at the inlet.

The oxidizer reaction zone temperature, outlet temperature, differential pressure, and flow rate were monitored during the source test. The data indicate that outlet temperature and differential pressure vary directly with flow rate, as anticipated. Reaction zone temperatures during Test Numbers 1 and 2 exhibited little fluctuation during the test runs. However, the reaction zone temperature at the beginning of Test Number 3 was 1582°F, which was below the normal setpoint of 1600°F. This lower reaction zone temperature was most likely the result of a higher than design flow rate through the oxidizer just prior to the test run. The flow rate was subsequently reduced to the design flow rate at the beginning of the test run. The reaction zone temperature increased steadily during the test run and was constant at 1599°F for the last 10 minutes of the run. VOC removal during Test Number 3 was comparable to the first two test runs and did not appear to be adversely affected by the slightly lower reaction zone temperature. Based on the three test runs, it appears that the PLC was able to maintain control of the reaction zone temperature near the setpoint while operating at, or near, the design flow rate of the unit.

The oxidizer operating parameters monitored during the source test are summarized in Table 3-2.

Table 3-1
Source Test Results

		Gaseous			Methane		Total Non-Methane Hydrocarbons[e]	
Test Number	**Date**	**NO_X[a] (ppm)**	**CO (ppm)**	**O_2 (%)**	**Inlet (ppm)**	**Outlet (ppm)**	**Inlet (ppm)**	**Outlet (ppm)**
1	6/23/95	0.68	1.8	18.5	310	<0.5[b]	11,000	0.89
2	6/27/95	0.72	2.2	17.6	2,150	<1.0[c]	10,350	0.54
3	7/6/95	0.55	1.9	17.6	3,700	<0.9[d]	12,000	1.17
Average	--	0.65	2.0	17.9	2,053	<0.8	11,117	0.87

Notes:
- a NO_X values corrected to 15 percent oxygen.
- b Methane not detected above method reporting limit of 0.5 ppm.
- c Methane not detected above method reporting limit of 1.0 ppm.
- d One of two methane results was detected below method reporting limit of 0.5 ppm.
- e Referenced to carbon.

Table 3-2
Oxidizer Process Data

Test Number	Date	Outlet Temperature (°F)	Reaction Zone Temperature (°F)	Pressure Differential (in. H_2O)	Process Flow Rate (scfm)
1	6/23/95	200.4	1600.2	0.697	4.69
2	6/27/95	222.8	1600.5	0.785	5.00
3	7/6/95	203.1	1594.5	0.772	4.96

Note: Operating data are averages of spot readings collected during test runs.

3.2.2 Comparison to Demonstration Objectives

A DRE was calculated for each test run (Radian 1995b). The average calculated DRE of 99.993 percent achieves the first PDO of a DRE greater than 99.99 percent. The DREs for each test run are summarized below:

- Test Number 1 DRE = 99.992 %
- Test Number 2 DRE = 99.996 %
- Test Number 3 DRE = 99.993 %
- Average DRE = 99.993 %

The average NO_x concentration in the oxidizer outlet was 0.65 ppm (corrected to 15 percent O_2), which is less than the PDO of 2 ppm NO_x. The average CO concentration of 2.0 ppm in the oxidizer outlet is less than the PDO of 10 ppm CO.

As described in Section 2.1, a secondary demonstration objective (SDO) was established to assess whether the operation of the flameless oxidation technology is acceptable and consistent with DON environmental and health and safety requirements. The following conditions were monitored in order to assess whether this SDO was met:

- the DRE planned under the first PDO was consistently achieved;
- power consumption required by the oxidizer unit was metered;
- emissions of NO_X, CO, and THCs were at acceptable levels (as stated above); and
- no operational incidents requiring services beyond those established in the Work Plan occurred.

Based on successfully meeting the conditions of the SDO, the operation of the oxidizer is considered "acceptable" and consistent with the DON environmental and health and safety requirements.

The demonstration also provided additional information on the operation of the thermal oxidizer. Requirements for operator attention were minimal, as the unit was designed to operate unattended. The combined electric power to the air compressor and the thermal oxidizer was metered. Average electrical power consumption during the demonstration period was 113 kilowatt-hours (kWh) per day. No safety or environmental incidents occurred during the demonstration.

3.3 QUALITY ASSURANCE AND QUALITY CONTROL

QC objectives for critical data were established to support the PDOs (BNI 1995). The quantitative QC parameters evaluated for this demonstration were precision and completeness. These QC parameters were applied only to the gas samples submitted for the analysis of methane and TNMHC. The percent recovery could not be evaluated as a measure of accuracy because analytical data required to perform the evaluation were not determined. The calculated precision and completeness parameters for methane and

TNMHC samples met the objectives established for this demonstration, with the exception of Test Number 3 precision. The quantitative QC parameters are summarized in Table 3-3.

Calculations of precision and accuracy do not strictly apply to the NO_X and CO measurements made during this technology demonstration. These measurements were made using continuous monitoring equipment. For NO_X and CO measurements, the following criteria were used to ensure accuracy and precision of the data: NO_2 to NO conversion efficiency, interference response, response time, zero drift, and calibration drift. These criteria and calculated QC parameters for NO_x and CO measurements are summarized in Table 3-3. The calculated parameters met all objectives, with the exception of NO_2 to NO conversion efficiency in Test Numbers 2 and 3.

The qualitative QC objective of comparability was satisfied by adherence to standard methods and guidance. The qualitative QC objective of representativeness was addressed by the sampling design implemented for the demonstration.

3.4 KEY CONTACTS

Key contacts for future reference regarding the NAS North Island Thermatrix technology demonstration are listed in Table 3-4.

Table 3-3
Summary of Quality Control Parameters

Quality Control Parameter	Objective	Actual	
Laboratory Analyses		**Methane**	**TNMHC**[a]
Precision	Duplicate analyses within 5% of mean value	Test 1: 0% Test 2: NA[b] Test 3: 17%	Test 1: NA Test 2: 0% Test 3: 8%
Accuracy	Audit samples within 10% of preparation value	No matrix spike samples were prepared for analysis	No matrix spike samples were prepared for analysis
Completeness	90%	Test 1: 100% Test 2: 100% Test 3: 100%	Test 1: 100% Test 2: 100% Test 3: 100%
Continuous Monitors		**NO_X**	**CO**
NO_2 to NO Conversion Efficiency	Greater than 90%	Test 1: 97.4% Test 2: 88.1% Test 3: 86.0%	Not Applicable
Interference Response	Less than ± 2%	c	c
Response Time	Maximum of 30 seconds for instrument and 90 seconds for system	c	c
Zero Drift	Less than ± 2% of the span value over each test run	Test 1: 0% Test 2: 0% Test 3: 0.2%	Test 1: 0.02% Test 2: 0.11% Test 3: 0.01%
Calibration Drift	Less than ± 2% of the span value over each test run	Test 1: 0.8% Test 2: -0.4% Test 3: 0.4%	Test 1: -0.1% Test 2: 0.5% Test 3: -0.13%

Notes:

a TNMHC – total nonmethane hydrocarbons
b NA – Not Available
c Interference response and response time tests were conducted within a 6-month period prior to source test.

Table 3-4
Key Demonstration Contacts

Organization	Contact	Responsibility
Department of the Navy	William Collins Southwest Division Naval Facilities Engineering Command 1220 Pacific Highway San Diego, CA 92132-5181 (619) 532-2337	NAS North Island NELP Management Team
	Doug Casey Southwest Division Naval Facilities Engineering Command 1220 Pacific Highway San Diego, CA 92132-5181 (619) 532-1448	Demonstration PM
	Mike Magee Naval Air Station North Island P.O. Box 357040 San Diego, CA 92135 (619) 545-1127	NAS North Island NELP Management Team
	Jose Casora Naval Air Station North Island P.O. Box 357033 San Diego, CA 92135 (619) 545-2431	Demonstration POC
Bechtel National, Inc.	Emile Houle 401 West A Street Suite 1000 San Diego, CA 92101-7905 (619) 687-8712	Project Manager NAS North Island Navy CLEAN II
	Dale Obenauer 50 Beale Street San Francisco, CA 94105-1895 (415) 768-0891	Demonstration Technical Lead
Thermatrix, Inc.	Robert Wilbourn 308 N. Peters Road Suite 225 Knoxville, TN 37922 (615) 539-9603	Director of Operations
	Marshall Allen 308 N. Peters Road Suite 225 Knoxville, TN 37922 (615) 539-9603	Demonstration PM

Section 4
CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations based on the NAS North Island Thermatrix thermal oxidizer demonstration are presented in this section.

4.1 CONCLUSIONS

The operation of the Thermatrix thermal oxidizer and the evaluation of the demonstration objectives are summarized in this section. In addition, capital costs and operation and maintenance (O&M) costs are discussed.

4.1.1 Thermal Oxidizer Performance

The analytical data support the PDOs presented in Section 2. The first PDO was to verify the effectiveness of the oxidizer technology as determined by a DRE greater than 99.99 percent, which was demonstrated. The second PDO was to verify that the oxidizer technology does not generate NOx emissions greater than 2 ppm and CO emissions greater than 10 ppm, both of which were also demonstrated. The SDO of assessing whether operation of the oxidizer technology is consistent with DON environmental and health and safety requirements was also demonstrated, as discussed in Section 3. Results of the technology demonstration indicate that the Thermatrix thermal oxidizer is capable of processing intermittent VOC streams and achieving VOC destruction greater than a DRE of 99.99 percent.

The operation of the oxidizer unit required minimal operator attention following commissioning and startup activities. No unit maintenance was required during the short-term duration of the demonstration. As discussed in Section 3, total electric power consumption to the air compressor and the electrically heated oxidizer was metered and averaged 113 kWh per day for the period of the demonstration.

No process residuals requiring treatment and disposal were generated during this demonstration.

Following the startup of the oxidizer, some difficulty was experienced with maintaining the reaction zone temperature at the design flow rate. Although the oxidizer unit adequately processed VOCs at near-design capacity during the source test, consistent operation at design conditions while processing a lean inlet stream may potentially be difficult to achieve. If an oxidizer unit is selected to process a lean VOC stream at ambient temperature, extra capacity may have to be factored into the selection of a unit.

4.1.2 Costs

Thermatrix representatives have indicated that the capital cost for the ES-300H oxidizer is approximately $50,000. Costs for larger capacity models would understandably be higher but would represent economies of scale.

Operating costs for the Thermatrix model ES-300H are essentially limited to the cost of electric power, since the unit was designed to operate unattended. Using an average power consumption of 113 kWh per day based on this demonstration and assuming $0.06/kWh, electrical power costs would be $6.78 per day or $2,475 per year. Note that this estimated power cost includes operation of an air compressor as well as the thermal oxidizer. Continuous operation of the oxidizer, rather than the intermittent operation experienced during this demonstration, would provide more heat absorption in the ceramic bed from oxidation reactions and would consequently result in less cooling from ambient air and a lower power demand for electrical heating.

For the purposes of evaluating this demonstration, it is assumed that periodic monitoring of the ES-300H during operation would require 0.5 manhours per day or 180 manhours per year. Therefore, using $35/manhour, the annual operations monitoring cost is estimated to be $6,300.

Maintenance of the ES-300H thermal oxidizer is limited to periodic inspection of the unit and to replacement of failed components. Periodic inspection of the unit includes the following activities:

- drain all water traps in compressed air lines;
- inspect all filters in compressed air lines and replace, if necessary;
- inspect oxidizer shell for weld failures or loose bolted joints;
- inspect thermocouples for visible deterioration or erratic response and compare with reference thermocouple;
- inspect knockout pot for deterioration, corrosion, and deposition of condensables;
- test high-temperature and high-level switches for functionality and check that the setpoints are correct;
- test safety limit devices in their failure mode to ensure proper operation;
- perform temperature controller self-diagnosis test; and
- test fume and purge solenoid valves for proper operation.

The system components most likely requiring replacement are thermocouples and temperature switches. Assuming that annual inspection and maintenance for the ES-300H are 5 percent of equipment capital costs, estimated maintenance costs are $2,500 per year.

While the ES-300H oxidizer is useful for demonstrating "proof of principle" for the Thermatrix flameless thermal oxidation technology, it is too small a unit to develop useful scale-up information for VOC treatment costs in terms of dollars per ton of VOCs removed. Thermatrix has provided a typical cost/benefit evaluation, which is included as Appendix C.

4.2 RECOMMENDATIONS

Additional testing should be conducted on an organic-rich stream or oxygen-deficient stream to further evaluate the operation of the oxidizer unit, particularly the dilution air system and its effectiveness in controlling the reaction zone temperature in the proper geometric location within the oxidizer. This testing is specific to the intended application of the oxidizer and could be conducted as a pilot-scale test prior to full-scale implementation.

Additional testing should be conducted on the thermal oxidizer at different operating conditions (i.e., inlet flow and reaction zone temperature) to establish limits for operating parameters that would ensure that emissions are not likely to exceed allowable levels. Testing to define this operating envelope could be conducted as part of a full-scale implementation to determine the most efficient operating conditions and to minimize power or supplemental fuel costs. If an operating permit is required by a regulatory agency for the installation of an oxidizer unit, definition of the operating envelope would potentially be mandatory.

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans are hazardous compounds which are sometimes present in emissions from thermal treatment processes. These compounds may be the result of dioxins and furans:

- present in the waste feed material which pass through the thermal treatment process without being destroyed,
- formed in the combustion process as products of incomplete combustion (PICs), and
- formed from chemically similar molecules, such as chlorinated aromatic compounds, or from chemically unrelated organic molecules in the presence of a chlorine donor, in the downstream gas cleaning system.

The third formation mechanism can be significant within a gas temperature of 300°F to 800°F, with maximum formation believed to occur between 500°F and 600°F. Combustion gas residence times in the order of seconds in this temperature window are thought to result in dioxin/furan formation.

PICs can be minimized by providing well-mixed conditions and sufficient excess oxygen at temperatures above 1500°F. The Thermatrix design incorporates these characteristics. However, in order to predict the formation of dioxins/furans, empirical information is needed from analytical tests on a particular unit under a specific set of operating parameters. Tests should be conducted on the thermal oxidizer with a chlorinated solvent feed stream to evaluate the resulting DREs, to determine the potential for formation of PICs, and to determine the need for a downstream acid gas removal system.

Section 5
REFERENCES

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